Improvement of the Cloud Physics Formulation in the U.S. Navy Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS)

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LONG-TERM GOALS

Correct representation of cloud processes is critical in producing accurate numerical weather prediction (NWP) forecasts. The major goal of the project is to develop state of the art parameterizations of cloud processes and implement them into COAMPS.

OBJECTIVES

Accurate formulation of cloud processes over a mesoscale model grid volume is hindered by inadequate parameterization of sub-grid cloud variability and poorly understood local conversion rates for cloud prognostic variables.

To resolve these present model shortcomings, we will develop the following parameterizations of cloud processes:

1. Parameterization for sub-grid saturation
2. A more complete formulation of cloud-aerosol interaction
3. A treatment of sub-grid variability for marine stratiform and convective clouds

APPROACH

Our research concerns direct improvements to COAMPS and a better understanding of its sensitivity to the treatment of cloud processes. In developing parameterizations of sub-grid variability and saturation for COAMPS, we have to build a bridge between sub-grid cloud properties and the resolved COAMPS fields. The domain of a large eddy simulation (LES) model can be configured to have roughly the same domain as a COAMPS grid cell, and is thus an ideal tool for exploring the parameter space among the resolved fields that dictates the character of the sub-grid variability. The LES can supply probability distribution functions (PDFs) of sub-grid variability for a wide variety of cloud fractions. A companion statistical study of millimeter-wave cloud radar data will also provide PDFs for use in COAMPS.

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COAMPS currently assumes relative humidity is constant inside a grid volume. In reality, cloud may be present in a region whose grid volume average relative humidity is less than saturation, and a grid volume average relative humidity of 100% need not imply uniform cloud cover. We are implementing a sub-grid saturation scheme of the form of Sommeria and Deardorff (1977), which is based on a statistical representation of sub-grid variability. The nature of the sub-grid distribution is determined by the mesoscale model sub-grid closure (TKE), so this sub-grid condensation parameterization requires a coupling of both microphysical and turbulence processes.

Because the concentration of aerosols strongly modulates precipitation and the persistence of vast regions of subtropical stratocumulus, a meaningful representation of aerosol in COAMPS should be included. The bulk microphysical parameterization we implemented into COAMPS includes a prognostic equation for bulk cloud condensation nuclei (Mechem and Kogan 2003). COAMPS is run in an idealized mode to characterize the cloud processing of aerosol and then compared to observations and results from LES studies. We will then explore sensitivity to surface, in-situ, and entrainment CCN sources. This approach will demonstrate which particular processes are most important in a mesoscale forecast and will provide insight into the best way to introduce remote sensing measurements of aerosol into mesoscale models once those measurements become routinely available.

WORK COMPLETED

The grant just began in February 2003, and a new scientist was hired in July, so the project is still in its early stages.

The following tasks have been begun:

1. Investigation of elementary cloud-aerosol interactions in COAMPS
2. Implementation of sub-grid condensation in COAMPS.

RESULTS

1. Cloud-aerosol interactions in COAMPS

As part of prior ONR-supported research, we implemented in COAMPS the bulk microphysical parameterization of Khairoutdinov and Kogan (2000), which includes prognostic equations for cloud, drizzle, and CCN number concentrations. Our preliminary results explore the basic behavior of the cloud-aerosol interaction in this parameterization. We have chosen an experimental configuration that allows simple closure on the CCN budget and easy interpretation of results. COAMPS is initialized in a 3D configuration with horizontally homogeneous temperature and moisture profiles with periodic boundary conditions and prescribed surface forcing. Various simulations are made with different initial CCN concentrations in the PBL, while free tropospheric air is assumed to have no CCN. These simulations will serve as a suite of control experiments upon which we can test sensitivity to surface, in-situ, and entrainment CCN sources.

Figure 1 shows the behavior of a simulation where initial CCN concentration is 200 cm^{-3}. The cloud top and associated inversion to ascend with time via entrainment, and the mean cloud thickness and liquid water content decrease. $N_{ccn}+N_c$ decreases with time, more quickly in the cloud layer where the aerosol processing is taking place. CCN in the sub-cloud layer is then transported upward to be processed by the cloud. By the end of the simulation, very few (< 10 cm^{-3}) CCN are present in the

upper part of the PBL, though this figure does not show that by this time the PBL has transitioned from a solid stratocumulus deck to a field of broken boundary layer cumuli.

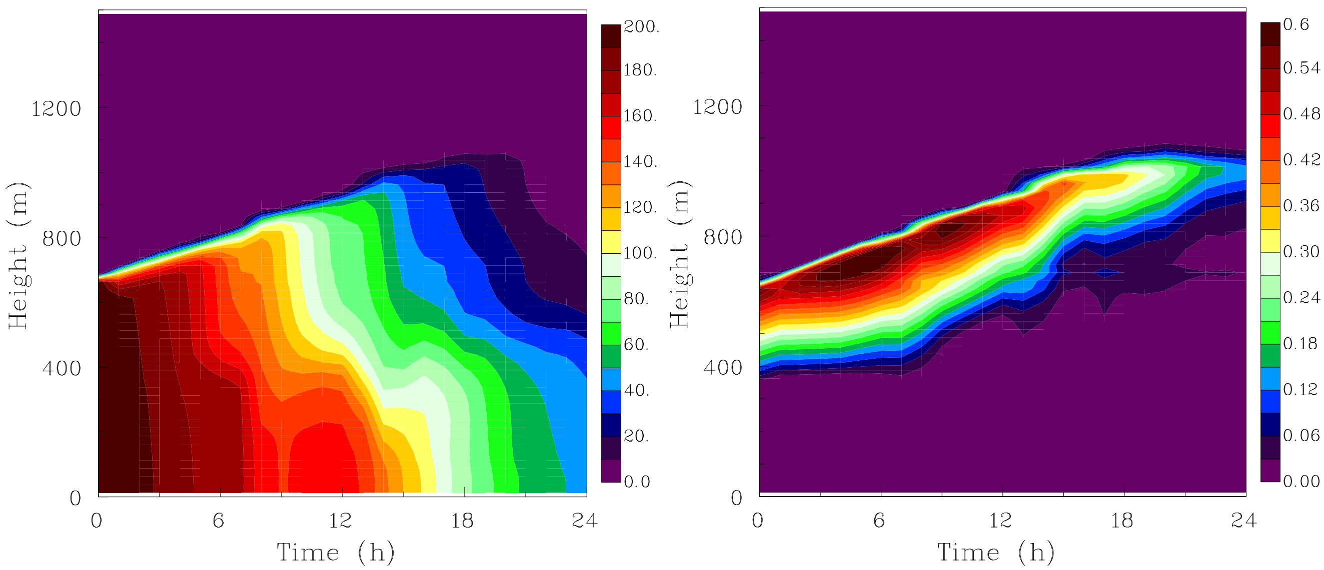

Figure 1. Time-height plots of horizontally-averaged q_c [g kg^{-1}] and N_{ccn}+N_c [cm^{-3}] for the control experiment with initial CCN concentration of 200 cm^{-3}. [graph: Cloud top increases in height from 662 m to 1050 m. Peak cloud water content decreases with time. Total particle number decreases with time.]

We wish to diagnose the depletion of CCN by the cloud system, but the decrease of N_{ccn}+N_c in Figure 1 arises not only from cloud processing but also from dilution via entrainment. A simulation with high aerosol load (800 cm^{-3}) in Figure 2 (left) shows a significant overall depletion (46% remaining) at 24 h, but much less depletion when dilution is taken into account (84% remaining). The cleaner case (200 cm^{-3}) shows a smaller difference between the total depletion and dilution, indicating a greater relative importance of cloud processing. The relative importance of cloud processing to total depletion is much greater in the clean case (up to 0.9), while in the polluted case entrainment dilution is the major factor in reducing the CCN with time. These differences arise not only because of the increased cloud processing in the clean case but also because the smaller liquid water content and cloud fraction reduces the entrainment and consequent dilution.

2. Parameterization of sub-grid condensation

Early results where the parameterization is applied to the microphysical processes show the most pronounced differences at cloud boundaries. Specifically, greater cloud coverage results, because the parameterization produces cloud in regions that are not saturated on the grid-scale.

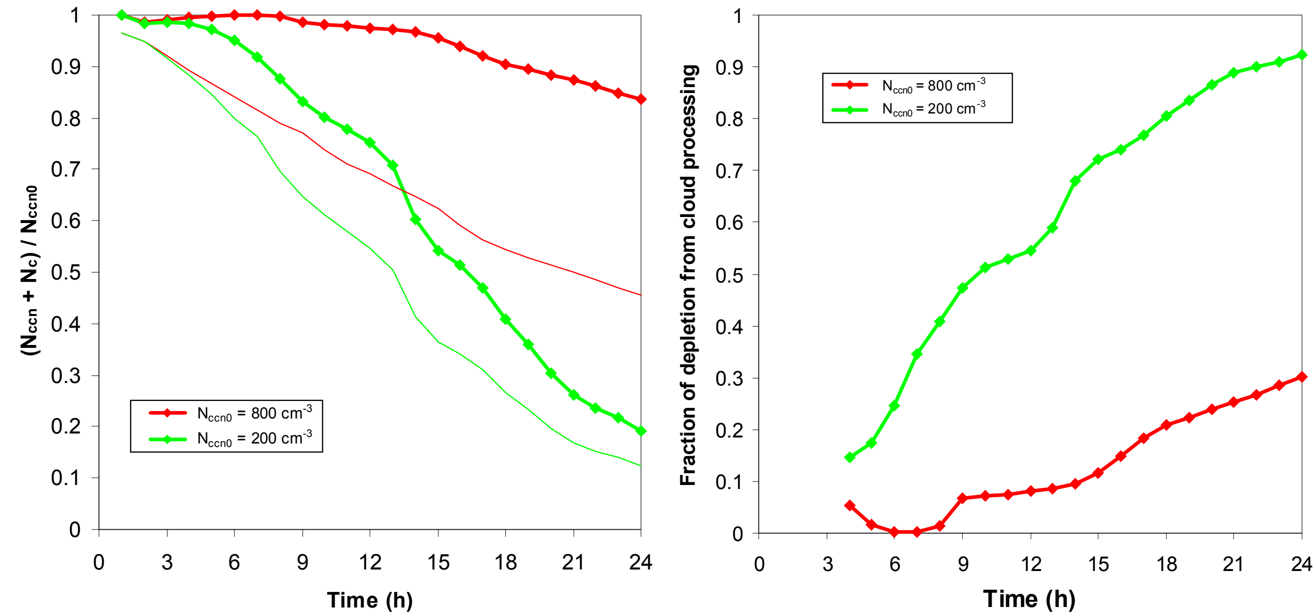

Figure 2. (left) Time series of N_{ccn}+N_c relative to initial CCN concentrations for two initial CCN values. Thin lines include dilution via entrainment, while thick lines represent only cloud processing. (right) Fraction of depletion due to cloud processing. [graph: relative N_{ccn}+N_c concentrations decrease over time, much greater when entrainment dilution is included. Fraction of depletion from cloud processing is greater in the clean case, and increases with time.]

IMPACT/APPLICATIONS

Improved parameterization of cloud physical processes will result in more accurate numerical weather prediction for U.S. Navy operations. Of relevance to the current results are more accurate forecasts of cloud persistence and radiative parameters.

RELATED PROJECTS

We plan to leverage our involvement in the Department of Energy Atmospheric Radiation Measurement Program (DoE ARM) for this project. Our ARM research involves using millimeter-wave cloud radar to measure spatial and temporal variability of cloud fields in order to derive PDFs for various cloud types. These observational PDFs will be integrated with those from LES results into our parameterizations for sub-grid variability.

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